Activity Guide

Power to Production

TSONGAS INDUSTRIAL HISTORY CENTER

University of Massachusetts Lowell
Graduate School of Education

Lowell National Historical Park

Connections to National Standards and State Curriculum Frameworks

Power to Production is an interdisciplinary program designed to help students achieve state and national standards in History/Social Science, Science and Technology, and Mathematics. The working of standards varies from state to state, but there is substantial agreement on the knowledge and skill students should acquire. The standards listed below, taken from either the national standards or Massachusetts standards, illustrate the primary curriculum links made in *Power to Production*.

History/Social Science

Students understand how the industrial revolution, the rapid expansion of slavery, and the westward movement changed the lives of Americans and led toward regional tensions. (National Standards)

Students understand the effects of inventions and discoveries that have altered for better or worse over time, working and safety conditions in manufacturing. (Massachusetts)

Students recognize the intended and unintended consequences of technological advances on the environment. (Massachusetts)

Science and Technology

Students develop an understanding about and abilities to do scientific inquiry: for example, observation, inference, and experimentation. (National Standards)

Students design an investigation or problem specifying variables to be changed, controlled and measured. (Massachusetts)

Mathematics

Students verify and interpret results with respect to the original problem. (Massachusetts)

Power to Production

Program Description

Power to Production consists of a 90-minute interpretive tour and a 90-minute hands-on workshop providing the students with the opportunity to explore the role of water power in the Industrial Revolution. On the tour, students discover the unique resources of Lowell National Historical Park firsthand. The hands-on workshop complements the tour by bringing the significance of these historic resources to life as students build their own water power systems.

Students tour the Suffolk Mill where they trace the transfer of water power from canal to turbine, and along the lineshafts, belts, and pulleys to a power loom producing cotton cloth. In the workshop, students examine the changes created by the development of Lowell's power canal system – the transformation of a pre-industrial farm community to an industrial city.

Theme

All that we consider "modern" was significantly shaped by the Industrial Revolution, whether it be in technology, politics, art, culture, or the nature of work itself.

Rushing water was the life blood of America's early industrial revolution. Countless mountain streams spilled together into the rivers of New England to create a vast source of potential energy. At a bend in the Merrimack River, bold men of vision captured this waterpower and built the most advanced power system in the world.

Program Objectives

After visiting Lowell National Historical Park and the Tsongas Industrial History Center and completing the activities of this guide, students will be able to:

- identify ways in which new sources of power and changes in technology brought about changes in the way people live, both historically and today.
- describe the differences in power generated by different types of waterwheels after conducting physical experiments using waterwheels, turbines and simple machines, and evaluating the results.
- describe the operation of a mechanized system of production after designing and constructing a system of power canals and visiting the Suffolk Mill.
- describe and illustrate ways in which human activities have had and continue to have a dramatic impact upon the environment.

Introduction

Imagine a cold, gray day in November, 1821. Several wealthy Boston merchants have been coaxed out of their comfortable homes to trudge through the snow of East Chelmsford. They are examining a potential manufacturing site on the Merrimack River. The site seems too far from Boston to be practical—nearly all of New England's commerce flows through Boston, 30 miles away. Then the merchants hear a noise, a roaring sound. Their curiosity is aroused. They round a bend in the river and see the Pawtucket Falls in full force. They know immediately that this force of nature will make them all fabulously wealthy.

. . . Such was the beginning of the nation's first large, planned industrial city: a city created because of a waterfall.

Building a Canal System

The original Pawtucket Canal was dug in the 1790s to go around the 32-foot falls. Barges carrying timber from New Hampshire floated down the river to Newburyport, a major center for shipbuilding. The first task of the Boston merchants was to enlarge this canal. They then constructed additional power canals to provide water for the newly built cotton mills. The first mill opened in 1823, and by 1848 there were ten major manufacturing corporations and more than 30,000 inhabitants in the young city of Lowell. The *entire flow* of the Merrimack River was channelled into the canal system to spin the water wheels which powered the mills.

The development of the canal system required impressive feats of planning and engineering. The most notable accomplishment was the construction of the Northern Canal in 1846-47. This last and most powerful canal increased the potential energy of the system by 50% and gave Lowell the largest power canal system in the world.

Capturing the Power

The Pawtucket Dam forces the water from the river into two large feeder canals. The water leaves the river *above* the falls, *before* it is allowed to take a 32 foot plunge. It was delivered to the mills, where it was dumped into basements containing water wheels. The weight of the water turned the wheels, which were in turn connected to machinery via shafts, belts and pulleys. This mechanical energy powered the machines.

Some mills used the full 32-foot drop by taking water from the main canal on the upper level and dropping it through water wheels directly into the river. Most mills, however, were built on one of two separate levels, which allowed the water to be used twice. After the water flowed through the wheels of the first, or upper mill, it was recaptured in a secondary canal. It was then delivered to a second mill and used again. In either case, gates in the canals controlled the flow of water to water wheels. Raising a gate turned a factory "on," while lowering it turned it off. All of the water eventually returned to the river in underground tailraces.

Traditionally, smaller mills used mill ponds to dam streams overnight to create an adequate source of power for mill operation during the day. Lowell's mills required so much water that the mill owners bought the water rights to Lake Winnipesaukee, a major source of the Merrimack River, located 60 miles away in New Hampshire. In essence, the entire lake became Lowell's "mill pond."

Making the System Work

When the river rose in the spring, water flowing through the wheels often backed up into the wheel pits causing "back water." This slowed the wheels, dramatically reducing their efficiency. In the 1840s, Lowell engineers Uriah Boyden and James B. Francis began designing and building turbines. A turbine is a special form of water wheel that operates under water. The turbine works well in both high and low water. By the 1860s, turbines had replaced almost all water wheels in Lowell.

High water not only affected the efficiency of mill operation but also posed a threat to the city itself. With canals running through the center of the city, it was necessary to take steps to prevent flooding caused by spring freshets and high waters on the Merrimack River. In 1850, a large floodgate was built near the head of the Pawtucket Canal. It has been dropped twice (1852 and 1936) to save the city from flood water.

Using the Lowell Canal System in the 1990s

Today the Lowell canal system is intact and looks much like it did in 1848. It functions as a power system (modern hydroelectric) for New England, a fishing spot for local residents, and as a transportation system for Lowell National Historical Park visitors. The Lowell canal system is a historic artifact reminding us of some of the many ways people use natural resources to alter the quality of life.

1. SITING A MILL

Getting Ready
Divide the class into groups of four students and give each a copy of the map on page 9 of this guide.

Setting the Scene
Read the following scenario to the class. Then discuss the facts that students need to remember to do the assignment. List these on the board.

> Each group represents a millwright who has been hired to build one water-powered mill located on this map. Several points must be considered when selecting the site:
>
> • The river is represented by the dark Y-shape on the map.
> • A dam is needed to collect water and create a mill pond.
> • A dam builder wants to build the dam as high as possible and as short as possible because long dams are expensive to build.
> • The dam must be level. Therefore, the two ends of a dam must meet contour lines with the same elevation.
> • A larger pond is better than a smaller one because it can store more water overnight.
> • A pond that is too big might not be worth creating if it floods too much good farm land.
> • The dam builder has to pay for the land flooded.
> • Most mills get power from water that drops 10 to 30 feet from the top of the dam to the bottom of the wheel.

Making the Decision
Ask students to figure out the high and low points on the map. Mark the two hills with an H and mark the low point with an L. Then figure out where to place the dam and mark it on the map. Follow the contour lines upstream from the top of the dam to figure the size of their mill pond. Use a ruler and the map scale to measure the length and width of the pond. Calculate the area covered by the pond. Is the pond mostly shallow or deep? Have students color in the pond.

Sharing the Decision
Have each group present its map and discuss the pros and cons of each solution.

2. FALLING WATER EQUALS POWER

In our Power to Production program, we emphasize how the early mill owners used the waterpower of the Merrimack River to run their machinery. But what must the water actually *do* in order to create this power? Water must fall vertically from a high to a low elevation, expending energy during its fall. The force of the water travelling downward through a distance creates power. This activity demonstrates that falling water can deliver power, and students can actually feel this power.

Getting Started

You will need the following items for this activity: six to eight clear plastic two-liter bottles; wide, clear packing tape; two plastic gallon jugs filled with water; a large dishpan (16-quart or larger); and a funnel.

Cut off the ends of the two-liter bottles and assemble them into a continuous tube. Secure each joint with tape. This is your waterfall tube. The entire tube should measure three feet. (If students bring in bottles, you can use the extras to build several tubes of varying lengths).

Feeling the Power!

To demonstrate that falling water has power, have two students support the waterfall tube vertically over the dishpan. Then:

- Carefully pour the gallon of water down the center of the tube, keeping the flow from the jug slow and uniform.
- Have students take turns feeling the pressure of the water at the top of the fall by placing two fingers one inch below the mouth of the jug.
- Have them compare that with the pressure of water hitting their hand directly beneath the tube.
- Ask students to predict what change they would feel in pressure if the pouring rate were increased. Run the gallon of water through the tube again, increasing the pouring rate. Were their predictions correct?
- Ask students to predict what change they would feel if you did not alter the pouring rate but doubled the height of the fall. To test their prediction, try using waterfall tubes of varying lengths.
- Students can use the funnel to refill the jugs as needed.

Conclusion

Students should understand that the power in a waterfall depends upon two factors: the height of the fall (the higher the fall, the greater the power), and the rate of the flow (the higher the rate, the greater the power). Ask students what other characteristics they think a waterfall might need in order to be a good power source for industry (for example, an available work force, nearness to port cities or railroads, enough land to support the building of a city, etc.).

3. CALCULATING THE POWER OF FALLING WATER

(recommended for students with some knowledge of pre-algebra)

During the previous activity, students learned that the power in a waterfall depends upon the height it drops (the *head*) and the rate at which it is pouring (the *flow*). The head is measured in feet and the flow is measured in cubic feet per second, or cfs. The power of the fall is the product of these two quantities times the conversion factor 0.113, which renders the product into the familiar units of horsepower:

power of the fall (hp) = head (in feet) x flow (in cfs) x 0.113

Your will need the materials from the previous activity, plus a stopwatch and calculator, to find the power of your classroom waterfall. Set the waterfall tube into position. Then:

- Have students use the stopwatch to time how many seconds it takes (run time) for you to pour the entire gallon through the tube.
- Calculate flow by dividing 1 gallon by the run time; this yields flow in gallons per second. Convert this to cubic feet per second by multiplying by the conversion factor 0.125 (cubic feet/gallon).
- Use the flow in cfs and the 3-foot head in the above equation to find the power in the classroom waterfall.

For Example . . .

Suppose it takes 30 seconds to pour 1 gallon of water through 3 feet. The flow in gallons per second is:

1 gallon / 30 seconds = 0.033 gallons per second

Convert this to cfs by multiplying by 0.125:

0.033 gallons per second x 0.125 cubic feet/gallon = 0.0042 cfs

Calculate the power using the equation:

3 ft x 0.0042 cfs x 0.113 = 0.0014 hp

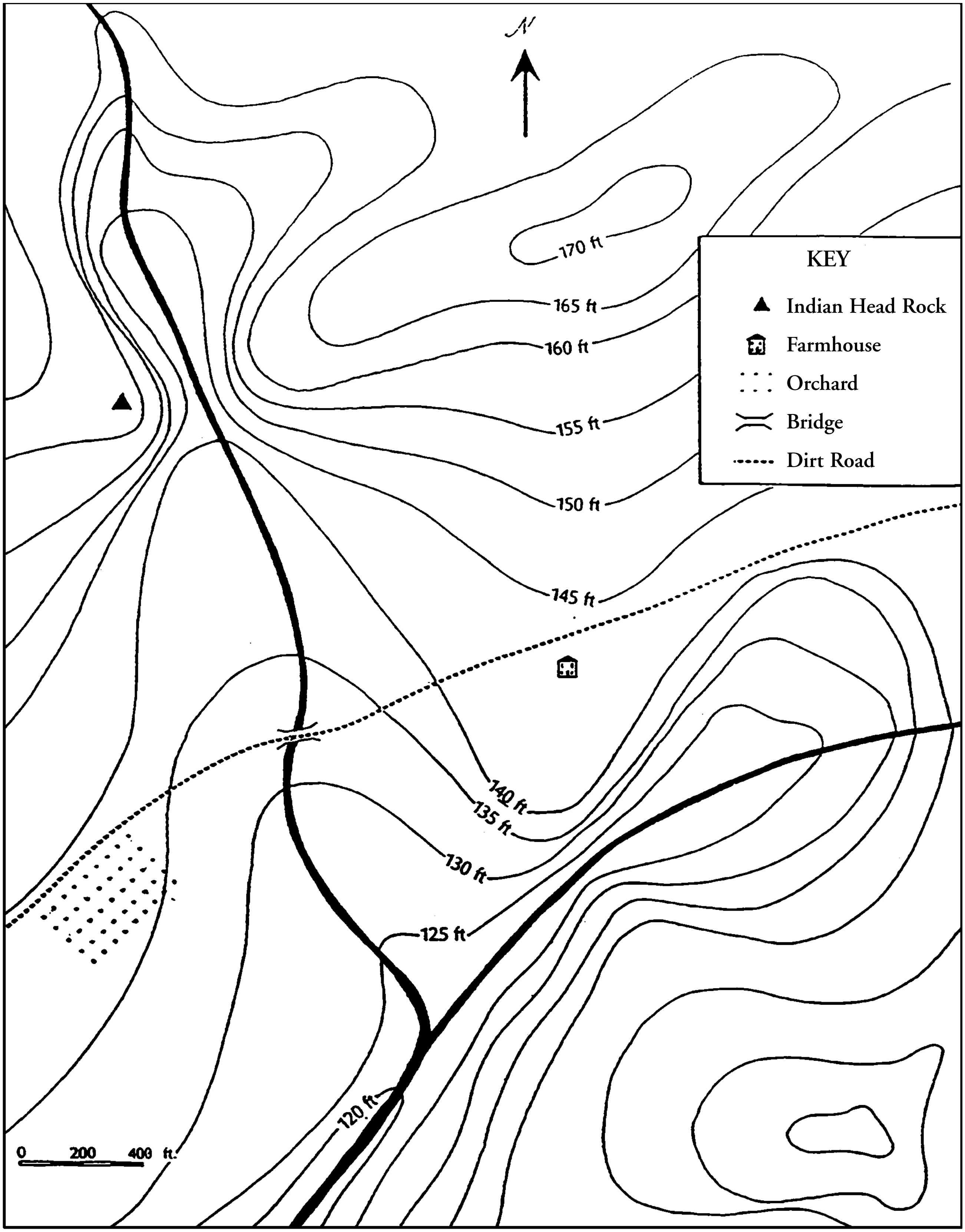
Students can get an idea of how much power this is if they consider the fact that a typical auto engine runs at roughly 100 to 150 horsepower. A car generates about 100,000 times as much power as their little waterfall!

What about the power in a real waterfall?

The Merrimack River drops 32 feet at Pawtucket Falls in Lowell. Its average flow is about 3600 cfs. How many horsepower is this?

32 ft x 3600 cfs x 0.113 = 13,018hp

No wonder the early mill owners looked with favor upon Pawtucket Falls as a source of power for their mills!


N
KEY
Indian Head Rock
Farmhouse
Orchard
Bridge
Dirt Road
170 ft
165 ft
160 ft
155 ft
150 ft
145 ft
140 ft
135 ft
130 ft
125 ft
120 ft
0 200 400 ft.

1. INCREASING THE WATER SUPPLY IN THE LOWELL CANAL SYSTEM

This activity challenges students to use information gathered during their Tsongas Center visit to advise James B. Francis on steps to take to increase the amount of water power available in Lowell in the 1840s.

Getting Started
Have the class form groups of four to six students. Each group will need to use research skills to solve the following problem.

Posing the Problem
Write the problem listed below on the board or copy it for each group.

> You are a group of advisors to James B. Francis, chief engineer of the Proprietors of Locks and Canals at Lowell. Locks and Canals is the company that originally built the power canal system and still owns the rights today. Water power has always been scarce in the dry summer months. However, by the 1840s, there are shortages throughout the year. James B. Francis is working on a plan to increase the amount of power available to the mills. His goal is to provide constant, year-round power to the mills. Your job is to help him decide how to accomplish his mission.

Pondering the Solution
List the following solutions on the board. Have the students consider the pros and cons of each solution.

1. Ban the use of water power for manufacturing at night so that there can be more stored up for use during the day.
2. Raise the height of the dam so that more water can collect behind it at night.
3. Gain control of the outlets of the major lakes that feed the Merrimack River to create reservoirs.
4. Build an additional canal from the Merrimack River to feed more water into the system.
5. Create underground tunnels between two or more canals to increase the amount of water to a section of the system.

Making the Decision
Have each group rank order the solutions from the best to the worst. Tell them to be sure to be able to defend their position. Post the rank order and pros and cons. Ask each member to vote for the solution he or she thinks is best. Discuss the results as a class.

Historically, all of these solutions were tried, and each was to some degree effective.

2. UNDERSTANDING AND COMPARING LEVELS OF WATER POWER

When students visited Lowell, they learned about the 32-foot drop in the Merrimack River at the Pawtucket Falls. All of the water from the river was diverted into canals before it reached the falls, and sent through canals to nearly 100 mill buildings where it turned water wheels. Clever engineers discovered that they could use the water twice: they dropped it 13 feet at the first mill, then recaptured it and channeled it through a lower level canal. It then dropped another 17 feet at a second mill before returning to the river (the remaining two feet helped move the water slowly from the upper river to the mills). After being used, all water returned to the river through underground tailraces.

Posing the Problem

Recall that falling water contains *potential* energy that can be used to do work and produce power. A cubic foot of water weighs about 62 pounds, and one cubic foot falling one foot can do one footpound of work. Power is the *rate* at which work is done. One horsepower is defined as 550 footpounds per second. To compute horsepower, multiply *head* (distance of drop in feet) times *flow* (cubic feet per second) times a *conversion factor* of 0.113 (62 pounds divided by 550 footpounds). To answer the following problems, use this formula:

Head x Flow x 0.113 = Power (hp)

During the program, students learned that Power = Money. Using this formula and the information in the table below, calculate the horsepower (hp) for each corporation.

Historical Information: Selected Textile Mills in Lowell: 1882

Corporation	Head (feet)	Flow (cfs)	Power (hp)
Appleton Co.	13	500	
Hamilton Co.	13	1000	
Suffolk Co.	13	400	
Boott Cotton Mills	17	800	
Massachusetts Mills	17	1200	

Finding Mathematical Solutions

1. Which company produces the most power? The least?
2. Rank the companies from most powerful to least powerful.
3. What percentage of the total power is produced by Massachusetts Mills?
4. Suffolk produces what percentage of Boott's power?
5. You are an investor who buys five shares of stock in a Lowell mill for $1,000 each in 1827. You expect to receive a dividend each year of at least $100 per share. Calculate your annual profit. What percent is this of the total cost of the stock?
6. Investors, such as Nathan Appleton, owned thousands of shares of stock in the mills. If Nathan Appleton owns 5,000 shares of the Lowell Co. (annual dividend $100 per share) and the average employee earns $200 per year, how much more does Nathan Appleton receive in dividends than the average worker earns in a year?

Answers:
1. Most—Mass (2305), least—Suff (588)
2. Mass, Boott, Ham, App, Suff
3. About 35%
4. About 38%
5. 10%
6. 2500:1

3. CAMS: MAKING SIMPLE CAMS AND CONDUCTING EXPERIMENTS

The early industrial revolution was powered by spinning water wheels. Early machines, such as spinning frames, required only rotary motion, so the transfer of power from wheel to machine was a simple matter. The power loom, however, needs linear motion—the shuttle shooting back and forth or the harnesses going up and down. A means to change rotary motion into straight-line motion was required. This device is called a *cam*.

A cam can come in many different shapes. For this exercise a cam is an eccentric or off-center circle; the axis on which the cam spins is offset from the center of the circle (see Fig. 1). It is relatively easy for students to grasp this important mechanical concept by making and testing simple cam sets. You will need the following materials for each set:

- A piece of foam core 12" square; four lids from 16 ounce margerine tubs; four pencils with erasers; four small wood screws; one round barrel ballpoint pen; household glue; ruler; screwdriver.

Getting Started

1. Locate and mark the center of each plastic lid. Mark the lids A,B, C and "wheel."
2. Make a mark on lid A one centimeter from the center; two cm for B; three cm for C. The distance from the center to each mark is called the *offset.*
3. Pierce each lid with a pencil through the marks you have made. Pierce "wheel" at center.
4. Insert pencils through holes in lids until metal eraser holders are touching lids. These pencils are the *camshafts.* Apply glue to metal on both sides of lids and allow to dry. The cams are now complete!

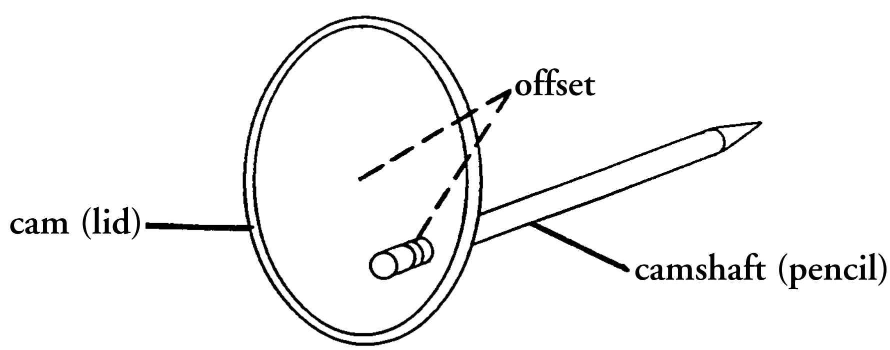


figure 1

Setting up the experiments

5. Mark a spot “X” on the cardboard that is 8” down from the top edge and 6” from the left edge. Draw a line from the X straight up to the top edge of the foam core.

6. Center the pen over the line just drawn and tape it lightly to the foam core. Insert two screws on either side of the pen near the top. The screws should hold the pen in place without impeding its vertical motion. This is your *cam follower* (see Figure 2). Remove the tape from the pen.

7. Take one of the cams and push the pencil tip through the foam core at point X. Enlarge the hole just enough to allow the pencil to turn freely. The cam should lie flat against the foam core. Insert the follower into its slot between the screws so that the pen base sits against the edge of the cam.

8. Hold the model up at an angle and turn the camshaft. The cam should rotate and the follower should ride up and down upon its edge. Adjust the screws if necessary.

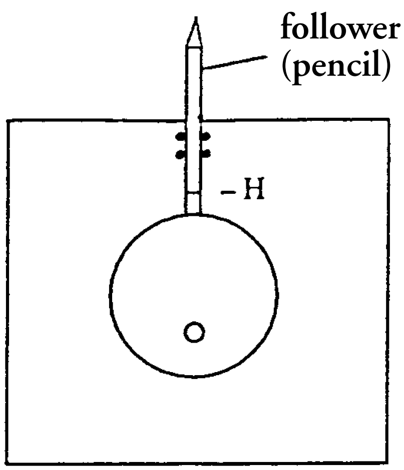


figure 2 (highest point)

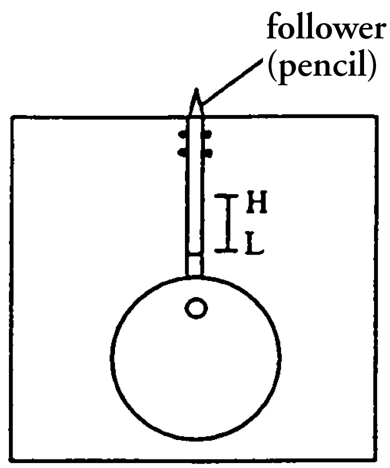


figure 3 (lowest point)

Does changing the offset of a cam change the distance the follower moves?
To answer this question, we must perform a four-step experiment. We will test each cam and record the movement of the follower on the chart below. Begin with cam A. Insert the camshaft through the foam core, and slowly turn the camshaft. Observe the movement of the follower. Make a pencil mark on the foam core to indicate the highest point (point H) and the lowest point (point L) of the follower's travel. Then use the ruler to measure the distance between the two points. Repeat for cams B and C and the wheel. Record your data on the chart.

	Offset (inches)	Follower movement (inches)
Cam A		
Cam B		
Cam C		
Wheel		

Interpreting Data
Ask students to study the data . See if they can discover a relationship between the offset distance and the distance the follower moved. Can this relationship be stated using a ratio? What is the ratio of follower movement to offset? (It should be 2:1).

Can this relationship be expressed using an equation?

follower movement = 2 x offset

Back to the Mill
During their visit to the Suffolk Mill, students saw many examples of mechanical devices. Among them were cams of various types. Ask students to recall where in the mill they saw cams being used. What jobs were the cams performing? What other machines can they think of that might make use of cams? What can they say about the overall significance of cams to the progress of the industrial revolution?

TERMS

back water - A condition that occurs when downstream water in the canal system rises and floods the wheel pits of the water wheels, causing them to slow down or stop.

canal - A human-made waterway used for transportation or power.

chute case - A turbine part which guides water from penstock to runners.

flywheel - A heavy wheel attached to machinery to regulate speed and maintain smooth rotary motion.

gatehouse - A structure on the canal with mechanisms to open and shut gates which control the flow of water to or from another canal or channel.

head - The height or vertical distance water falls to supply a mill with power.

headrace - A channel which carries water to a mill.

Industrial Revolution - The period of time when people started to make products using machines in factories, instead of making things by hand.

integrated manufacturing system - A system of manufacture in which all aspects of production take place under one roof.

line shaft - A long bar which transfers power from the flywheel to individual machines by means of pulleys.

Millwright – A person who designs or builds mills, or installs mill machinery.

operative - A factory worker responsible for tending machines.

penstock - A tube or tunnel used to bring water from canal to turbine.

power loom - A machine used to weave cloth; run by something other than human power.

runner - A turbine part; blades propelled in a circular motion by the force of water.

tailrace - A channel which carries water from the mill back to the river or to another mill.

technology - The ideas and tools which enable people to do the things they want to do and make the things they want to have.

turbine - An improved instrument for harnessing water power; 80%-90% efficient; works underwater, so is less affected by back water.

water power - The power of falling or running water used to drive machinery; the greater the weight of falling water, the more available power.

water wheel - An early device which uses the weight of falling water to generate power; 40%-60% efficient; subject to the effects of backwater.

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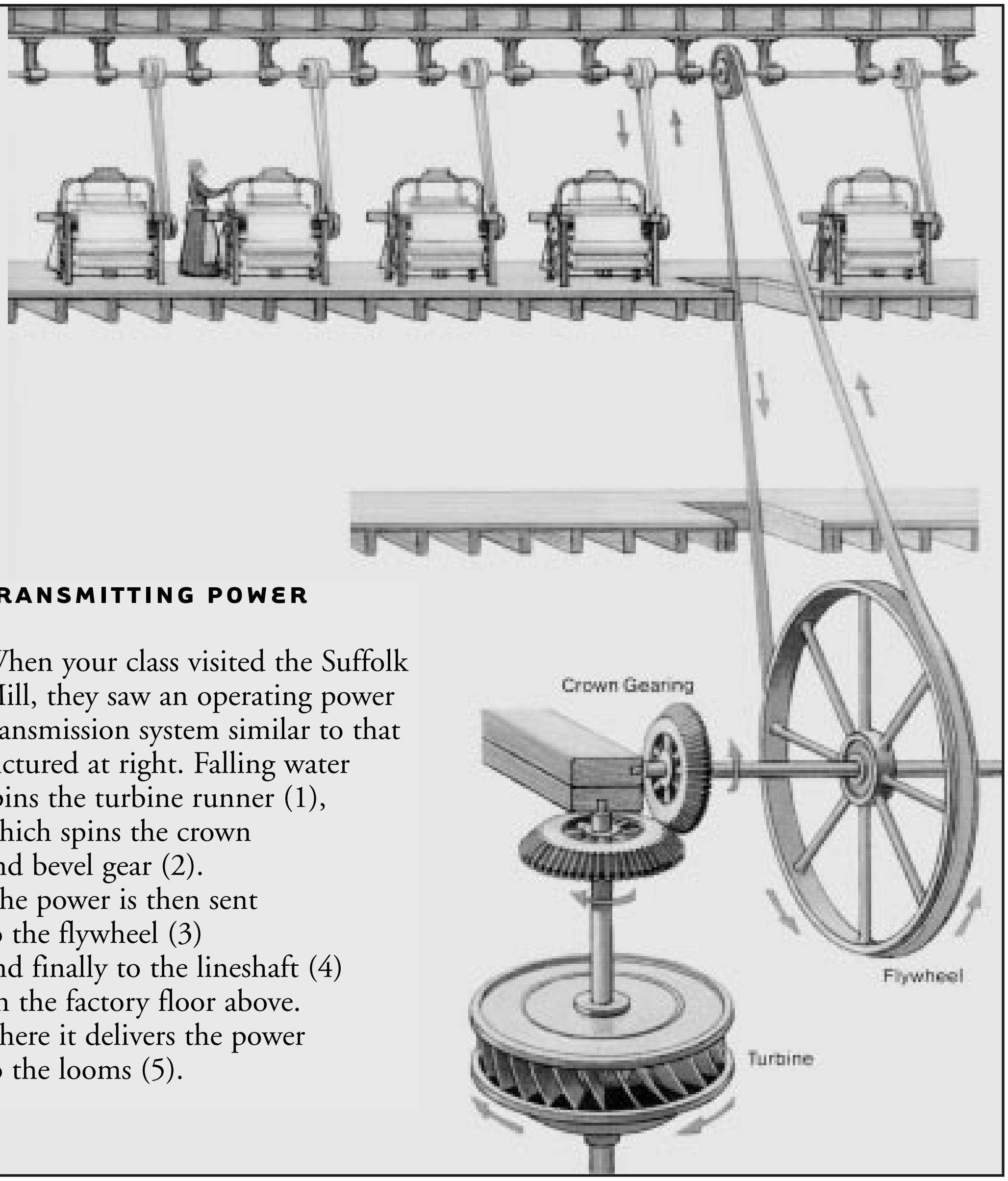

TRANSMITTING POWER

When your class visited the Suffolk Mill, they saw an operating power transmission system similar to that pictured at right. Falling water spins the turbine runner (1), which spins the crown and bevel gear (2). The power is then sent to the flywheel (3) and finally to the lineshaft (4) on the factory floor above. There it delivers the power to the looms (5).

The Tsongas Industrial History Center is a joint educational enterprise sponsored by the University of Massachusetts Lowell and Lowell National Historical Park. Established in 1987, its goal is to encourage the teaching of industrial history in elementary and secondary schools.

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